

**POLYMER NANOCOMPOSITES BASED ON FUNCTIONALIZED CARBON
NANOTUBES**

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ABSTRACT

The applications of polymer can be reached world widely including the thing we used to write, to wear, to communicate, to sleep and so on. Never imagine the day without polymer, whole world will stop moving without it. Nowadays, scientist and engineer are trying hard to make further improvement to the polymer properties such adding of nanofiller for better applications in human's life. Carbon nanotube (CNT) is an allotrope of carbon that found to be nanofiller that able to enhance the properties of original polymer. The objective of this research is to identify the improvement of the properties on polycarbonate (PC) by adding CNT as additive. The experimental parameters of this research included the composition of the CNT and treated CNT in matrix of PC. In this study, surface treatment that been carried on CNT is known as functionalized of CNT which to make the function of CNT in PC matrix become more apparent. There were two main research procedure which included sample preparation and characterisation based on the test that been carried out. Melt mixing technique by twin screw extrusion had been used for mixing and dispersion of CNT purpose. The samples in dumbbell shape that used in characterisation are been produced by using the injection moulding. The standard mould, ASTM D638 is been used as it is a standard dumbbell for mechanical testing. Several testing were carried out to characterize the properties of the sample that been produced, the testing included chemical resistance test, mechanical test and last but not least was weathering test. Some the pellet samples from twin screw extrusion were used for the chemical resistance test while others used to produce dumbbell sample for mechanical test and weathering test. The chemical resistance test was carried out by submerged the pellets sample into a beaker of chemical. While the mechanical test were carried out by universal mechanical testing machine, tensile strength and elongation of material were analysed based on the data obtained. Whereas the weathering test was carried out by using accelerated ultraviolet (UV)/ weathering system. One year period of UV exposed had been set and the changes in mechanical properties of the sample were investigated by the mechanical testing. Based on the result obtained, the properties of PC with treated CNT composite gave the most satisfied result. The addition of treated CNT not only improves the resistibility of PC towards chemicals, it also increases the mechanical properties and reduces the effect after weathered. The recommendation for future research of this topic is increase the amount of treated CNT in PC matrix which can give better reinforcement effect to PC.

Key words: Carbon nanotubes, functionalized, surface treatment, reinforcement

ABSTRAK

Aplikasi polimer kini telah mencapai suatu tahap di mana seluruh dunia sedang menggunakannya. Ia telah menjadi suatu rutin kehidupan, ini termasuklah barangan yang digunakan untuk menulis, dipakai, komunikasi, tidur and sebagainya. Sehingga hati ini, para saintis and jurutera masih berusaha menambahbaiki ciri-ciri polimer yang sekian ada sekarang. Penambahbaikan yang dikatakan adalah seperti pengisian ‘nanofiller’ ke dalam polimer asal. ‘Carbon nanotubes’ (CNT) adalah alotrop karbon yang didapati menjadi ‘nanofiller’ yang boleh mempertingkatkan ciri-ciri asal polimer. Justeru itu, objectif kajian ini ialah untuk mengenal pasti penambahbaikan kepada ciri-ciri asal polimer polikarbonat (PC) dengan mengguna CNT sebagai pengisi. Parameter ujikaji yang ditetapkan ialah komposisi CNT and komposisi CNT yang permukaannya diubahsuaikan. Dalam kajian ini, pengubahsuaian permukaan CNT dikenali sebagai pengfungsian CNT di mana permukaan CNT diubahsuai supaya CNT tersebut berfungsi sebagai pengisi yang lebih baik. Terdapat dua prosedur kajian yang utama iaitu penyediaan sample dan penyifatan sample selepas ujian dijalankan. Teknik pencampuran lebur dengan menggunakan ‘twin screw extrusion’ untuk tujuan pencampuran dan penyebaran CNT. Sampel dengan bentuk dumbel mengikut piawai ASTM D638 dihasilkan dengan menggunakan ‘injection moulding’. Beberapa ujian diadakan untuk menguji parameter yang ditetapkan. Ini termasuklah ujian ketahanan terhadap bahan kimia, ujian mekanikal and ujian ketahanan terhadap cuaca. Sesetengah butiran sampel yang dihasilkan daripada ‘twin screw extrusion’ digunakan untuk ujian ketahanan bahan kimia, manakala yang selebihnya diprocess untuk dijadikan sampel dumbel bagi ujian mekanikal dan ujian ketahanan terhadap cuaca. Ujian ketahanan terhadap bahan kimia dijalankan dengan merendam butiran sampel ke dalam bahan kimia. Manakala, ujian mekanikal dijalankan dengan menggunakan ‘universal mechanical testing machine’, kekuatan tegangan dan pemanjangan akan dianalisis berdasarkan data yang dikeluarkan. Ujian ketahanan terhadap cuaca dijalankan dengan menggunakan ‘accelerated ultraviolet (UV)/ weathering system’. Pendedahan kepada sinaran UV sepanjang selama setahun ditetapkan dan perubahan ciri-ciri mekanikal dianalisis. Secara keseluruhannya, berdasarkan keputusan ujian yang dijalankan, didapati bahawa CNT yang diubahsuai memberi peningkatan kepada ciri-ciri asal PC. Penambahan CNT yang dirawat permukaannya telah menambbaiki ketahanan terhadap bahan kimia, meningkatkan ciri-ciri mekanikal dan mengurangkan kesan hakisan cuaca. Cadangan yang diberikan untuk kajian masa depan ialah meningkatkan kuantiti CNT yang diubahsuai supaya ia dapat mengukuhkan lagi polimer PC and memberi ciri-ciri yang lebih baik.

Kata kunci: Carbon nanotubes, pengfungsian, pengubahsuai permukaan, mengukuhkan

CHAPTER 1

INTRODUCTION

1.1 Background of Study

The superior properties of carbon nanotubes (CNTs) contribute to development of new composites. Since the discovery of CNTs, many further investigation of its properties been carried out significantly. It found to be the filler used for most of the polymer based composites. Its filler-based applications giving a great promise in reinforce a material in terms of their conductivity, strength, elasticity, toughness and other mechanical properties (Leer et al. 2005). In another words, due to its remarkable mechanical and other physical properties, it have attracted particular researcher and industrial interest (Shaffer et al, 2002). CNTs have been good candidates for producing new functional composites and they may be the next generation of carbon fibers (Shaffer et al, 2002). Based on previous research, CNTs filler successfully will give a remarkable improvement on the polymer composite. On the other words, the weakness in the pure material is been recovered by the CNTs.

Reinforcement of CNTs in polymer offering an excellent product of polymer nanocomposites, but unfortunately to obtain excellent polymer nanocomposites is very tricky. Disaggregation and uniform dispersion are critical challenges that must be overcome in order to produce high property composites (Vaisman et al. 2007). Muthuraman Harish (2005) had added that a good dispersion of the CNTs in polymer matrices play critical role in transferring the better-quality properties of the CNTs into the nanocomposite materials with expectant and reproductive properties and performances. Without proper dispersion, fillers tend to aggregates and act as defect sites which limit the mechanical performance; such agglomerates also adversely influence physical composite properties such as optical transmissivity.

There are three methods of dispersion that usually used to introduce CNTs into polymer which are solution mixing, melt mixing and in-situ polymerization (Li et al., 2005). Different methods will gives difference results on the properties characteristics due to difference degree of dispersion. On the other hands, the ability to produce a homogenous dispersion of CNTs can be achieved by chemically altering the nanotube surface to increase the polymer-nanotube interaction (Weisenberger et al., 2007).

Polymer nanocomposites based on filler carbon nanotubes are produced widely nowadays since the advantages of the nanocomposites are recognized and proved by many researchers. In some case, pure material unable to fulfil the specific requirement in term of either mechanical properties or physical properties, thus by additional of filler, a new product with better properties can be obtained. Adame et al. (2009) said that CNTs in polymer able to increase the resistance of the polymer. At the same time by adding CNTs, the mechanical properties of the virgin polymer can be enhanced.

1.2 Problem Statement

Generally, PC has low resistance towards chemical as it is usually used in condition less contact with chemicals. This is one of the weaknesses of PC that need to overcome to widen future demand. The research on addition of CNTs in the PC resin might help to overcome this problem and give also better properties. Besides, CNT is

well-known as good filler that can reinforce the mechanical properties on a polymer. The mechanical properties might be able to be further improved by addition of this additive. In this study, experiment will be carried out to prove the ability of CNTs to improve the mechanical properties of PC. Commonly, plastic and other material will degrade after exposed to ultraviolet radiation. Loss weight and reduction in the mechanical properties are among the effect of weathering. Research is required to investigate whether addition of CNTs will help in reduce the effect of weathering.

1.3 Research Objective

To identify the effects of addition of carbon nanotubes (CNTs) to the properties of pure polycarbonate (PC) polymer.

1.4 Scope of the Research

Research scope is very important to ensure the objective of the research is achieved. In general, the scopes are used as a guideline for conducting the research in a correct pathway. The scopes of this research are summarized as follow:

- i. Polycarbonate is the raw polymer that used in the research which the properties of PC will be identified after addition of CNT.
- ii. Multiple wall nanotubes (MWNTs) with specification of 20-40 nm in diameter and 10-30 μm in length is one of CNT types that been used to reinforce the pure PC.
- iii. The parameters of the research are as 100wt% PC, 99.5 wt % PC-0.5 wt % treated CNTs, 99.5 wt% PC-0.5 wt% untreated CNTs and 99.0 wt% PC-1.0 wt% untreated CNTs.
- iv. Surface treatment was carried out on the CNT and it is know as functionalised CNT.
- v. Chemical resistance tests, mechanical test and weathering test were the test that been carried out to identify the effect of addition of CNT in PC polymer.
- vi. The period of chemical resistant test was set as 1 hour, 3 hour and 24 hour.

- vii. Scanning Electron Microscope (SEM) analysis was carried out to characterize the defect on the samples.

1.5 Rationales And Significances

The main purpose of this research is to enhance the properties of pure PC. Addition of CNT as additive believes can enhance the properties of pure PC and thus produce a better quality product. The pure PC had a strong mechanical property but weak in chemical resistance and low resistance towards effect of weathering. By adding CNT nanoadditive, it will strengthen the strong mechanical property that originally exhibited by the pure PC and gives a better chemical resistance and weathering property as well. Thus, PC/CNTs composite become demand in future to replace the existing pure PC products. Consequence of better quality of material production, the quality of society's life is also increases. The non-stop upgrading and advance research on the properties of the composite developing innovations and also increase the creativity of researcher to produce better product. Besides that, production of composite is more economical if compared to production of pure PC polymer product. This can be explained by which the better properties of composite product can be sold out with higher prices while the quality of CNT additive used in small amount. The production of composites is not really complicated to have too huge economic gap if compared to pure PC polymer production. As more purchase of composite product, it would helps to increase and stabilize economy of country also. In conclusion, the production of PC/CNT composite research able to bring a lot of advantages not only to the customer and country, the researcher will get the return as well.

CHAPTER 2

LITERATURE REVIEW

2.1 Polycarbonate (PC) Polymer

PC resin is known by trademarked name, which are Lexan, Makrolon or Makroclear. More specifically PC is polycarbonate of 2, 2-bis-(4-hydroxyphenyl) propane or bisphenol A (BPA) (Lister, 2010) which is a type of polyester of carbonic acid and dihydric phenols. Bisphenol A is a monomer of PC. It usually formed by condensation reaction of phenol and acetone under acidic conditions (Barbalata, 1996). Another alternatives method to produce BPA is by condensation of phenol with phosgene in an aqueous of sodium hydroxide (NaOH) solution.

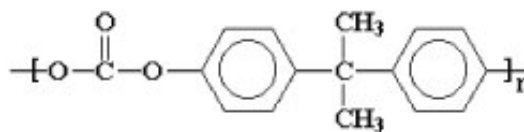


Figure 2.1: Structure of polycarbonate

Source: Lister, 2010

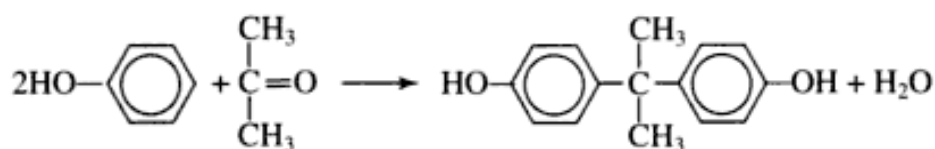


Figure 2.2: Bisphenol A production mechanism

Source: Barbalata, 1996

Two processes are available for the synthesis of PC which is ester exchange and phosgenation (Barbalata, 1996). However, ester exchanges process most commonly used in industry of manufacturing. The ester exchange process is that involved catalyst and transesterification of diphenyl carbonate with BPA in the melting solution. The catalysts usually used in this process are hydroxides or hydrides of alkaline metal and zinc or antimony oxides. The process of making PC by ester exchange process is called as condensation polymerization, by which diphenyl carbonate molecules will be eliminated.

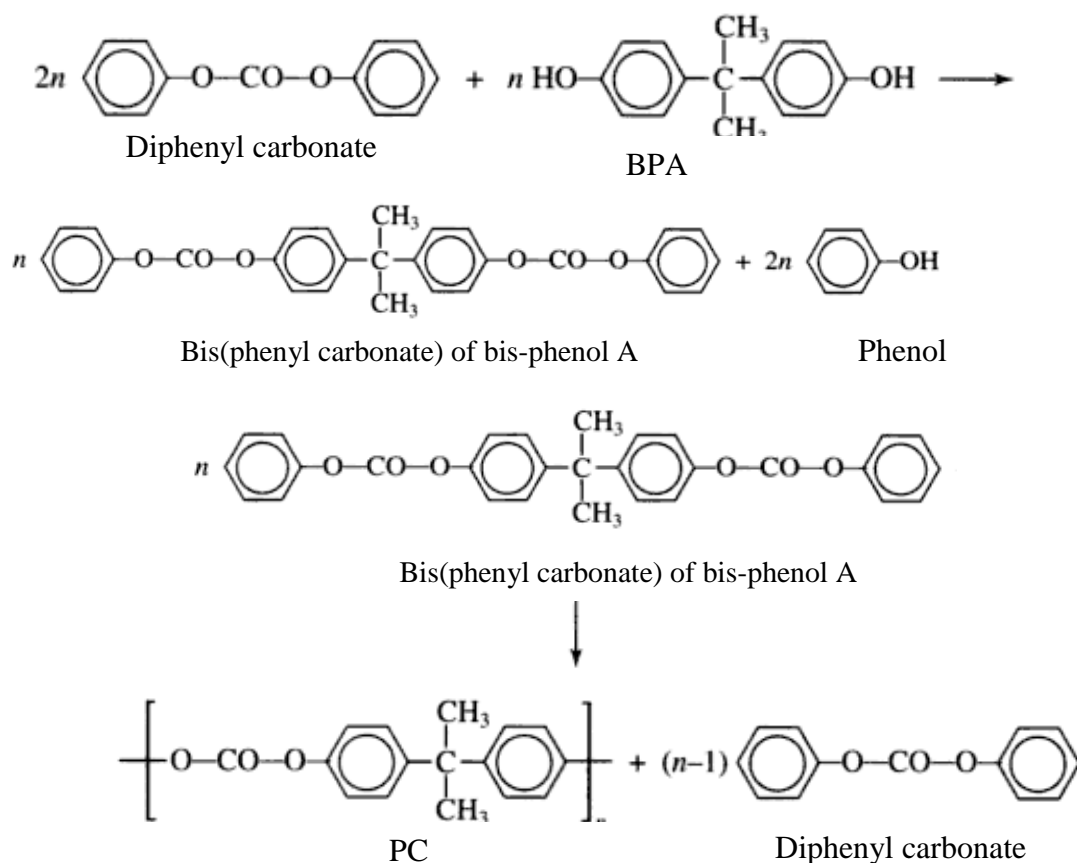


Figure 2.3: Polycarbonate production mechanism

Source: Barbalata, 1996

The PC monomer molecule consists of methyl and phenyl group. The presence of the phenyl group and methyl side groups in the molecular chain contributes to molecular stiffness in the PC. The strong bonding of the phenyl groups between different molecules reduce the mobility of molecules in PC, thus, it gives good thermal resistance properties. Lacking of mobility and flexibility cause the PC from further developing a significant crystalline structure and this allows for light transparency.

In 1999, Lehman and his co-workers had clearly clarified about the mechanical properties and chemical resistance of PC. They had described PC as an extremely tough

thermoplastic with outstanding strength, dimensional stability and electrical properties, high heat distortion temperature and low-temperature and so on. This is one of the reasons that PC is widely used as engineering plastic. Besides that, Zhang et al., 2007 mentioned that PC is insensitive to moisture and durable to various weathering conditions. All above are the advantages of PC that been found by experimental observation, however, PC also have disadvantages. One of the disadvantages that been mentioned by Lehman et al. is PC have fairly resistance towards chemicals especially to strong acids and bases, organic solvents and aldehyde compounds. This statement had been proved by the stress cracking that caused by solvents attacks.

The good properties of PC make them widely been used in many applications. Its high transparency and transparency very suit for it to be used in the field of lighting of electrical (Platt, 2003). The lamp covers by PC material offers optimum radiant efficiency. On the other hands, this material is having high level of impact strength which provides extensive protection from the accidental damage. It is used to manufacture traffic light signal panels, globe lamps and other types of electric light covers. PC also used to make ophthalmic lenses due to its high refractive index (V.S.Sastri, 2010) that enables production of thinner lenses. The PC lenses offer superior impact resistance that reduces the lenses broken crisis. Another application of PC are such as mobile telephone, desktop, calculator and tubing connectors as PC are high impact strength, flame retardant, high heat resistance and good surface finishing (Platt, 2003).

PC is a high performance polymer as it has unbeatable strength with light weight. Unfortunately it has certain severe weaknesses, such as poor weather-ability (Polymer Processing.com, 2001), chemical resistance and process ability (I.S.Bhardwaj, 1994) which limit its marketability. After years and further research, PC/CNTs composite were introduced to public. The researchers believe that this composite able to retain the outstanding mechanical properties of PC, however at the same time reduce the weakness in PC.

2.2 Carbon Nanotube (CNT)

CNT is an allotrope of carbon molecule with nanostructure. In 2007, Vaisman et al. had explained that each atom in graphite is connected evenly to three carbon atoms (120°) in xy plane and weak π bond is present in the z-axis. This phenomenon called as sp^2 hybridization. The sp^2 hybridization forms the hexagonal lattice of a sheet of graphite. The electrons in p_z orbital are localized within this cloud and this produce a kind of interactions called Van de Waals forces (Terrones et al. 2003). This had explained that graphite can conduct electricity, except diamond because all the electrons are localized in the bonds within sp^3 area (Knupher et al. 2001) as shown in Figure 2.4. The delocalized of π –electrons in graphite promoting high conductivity.

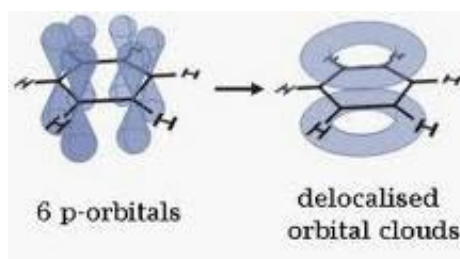


Figure 2.4: Delocalization of electrons

Source: Knupher et al. 2001

There are two basic categories of CNTs which are Single Wall Carbon Nanotubes (SWNTs) and Multi Wall Carbon Nanotubes (MWNTs). The Multi-Wall Carbon Nanotubes (MWNTs) consisting of two or more seamless graphite cylinders that concentrically nested arranged. The MWNTs separated $\sim 0.34\text{nm}$ from adjacent shell, $\sim 1\text{nm}$ diameters and high length/diameter ratio (Rupesh et al. 2005). They also mentioned that SWNTs are consists of seamlessly cylindrical tube and made of single graphite sheet. The structures of SWNTs and MWNTs are illustrated in Figure 2.5.

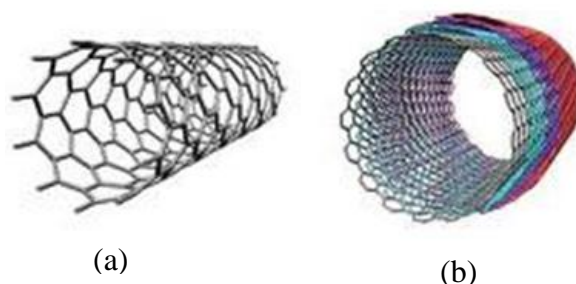


Figure 2.5: Structures of (a) SWNT and (b) MWNT

Source: Rupesh et al. 2005

The mechanical properties of CNTs are also dependent on the structure of the nanotubes due to the anisotropy of graphite. Further described by L. Vaisman et al in 2006, mechanical properties of SWNTs usually exceed those of MWNTs. The smaller size and massive arrangement in ropes-kind of SWNT make the measurement more complex and less precise. Rupesh et al. (2005) mentioned that they had expected that CNTs to have high stiffness and axial strength as result of sp^2 hybridization bonding. In 2006, Vaisman et al. that their outstanding characteristics including remarkable flexibility, excellent thermal and electrical conductivity and high aspects ratio which means length to diameter ratio.

Since the discovery of first CNTs by Sumino Iijima, the high performances of CNTs were investigated further. In 2002, Raouf O. Loutfy et al. had found that inherently superior mechanical properties of CNTs coupled with polymer will have composites with excellent potential in term of mechanical properties. This development expands the range of applications of nanocomposites in which they are widely used in nanometer-electronic devices, field emission devices, sensors and probes (H.Baughman et al., 2002).

2.3 CNT Functionalization

The functionalized CNT is a term to describe the surface treatment on the CNT in order to produce an enhanced composite. Surface treatment or chemical modification is usually carried out by the most basic method which is oxidation of CNTs (N.Tchoul et al., 2007). Jin et al. in 2005 shows that some of the physical and chemical properties of CNT/polymer composites are not enhanced significantly. This is due to the weak interfacial bonding between the CNTs and the polymer matrix. They believed that by treated the CNTs with acidic solution enables the impurities removal and improves the interfacial bonding and dispersion of CNTs in the polymer matrix (Jin et al., 2006)(N. Tchoul et al., 2007). Besides, they also mentioned that chemically modified CNTs are more soluble and easily incorporated into the polymer matrix.

As been mentioned before, CNTs having structure like web matrix as been shown in figure 2.5. The wetting properties of CNTs could significantly improved by oxidation by strong acids such as sulphuric acid and nitric acid or a mixture of acids (Vaisman, 2007). He believed that the oxidation cause the formation of carboxylic functional group (-COOH) at the end of the CNTs cap, where that regions located more strain with higher chemical reactivity. The end caps of CNTs are then opened and acidic functionalities which suitable for further entanglement, dispersion and solubility in water and organic solvents.

However, incorrect oxidation method will damages CNTs in which cause defects in structure of CNTs, shortening the tube length, accumulate of impurities and loss of material (N.Tchoul et al., 2007). Nitric acid is the most frequent agent used for oxidation of CNTs (N.Tchoul et al., 2007) and supported by research done by Wang et al. in 2008.

2.4 Dispersion of CNTs in Matrix of PC

C.H. Kiang et al. (1998) reported that composite materials that been reinforced by either SWNTs or MWNTs give significant enhancement in mechanical properties. In another words, CNTs are good filler in polymers. The composite with low concentration of CNTs is enough for a numerous applications (Pravin V. Kodgire et al. 2006).

Based on Vaisman and his co-workers research in 2007, in order to produce high property materials, the most critical challenges are the disaggregation and uniform dispersion. In 2010, Nanda Gopah et al. found that CNTs extremely hard to disperse and align it into a polymer matrix because CNTs form stabilized bundles due to Van der Waals interactions. The CNTs tend to self-associate into micro-scale aggregates. The SWNTs tend to form into bundles or ropes due to the Van der Waals forces, this making them difficult to disperse individually into polymer matrix (Weisenberger et al., 2007). On the other hands, can be dispersed easily but tensile stress is weakening due to weak intershell bonding. Again, Vaisman et al. also highlighted that if the dispersion is poor, the mechanical properties will probably decrease relatively to pure polymer.

Chemically altering the CNTs surface can enhance the degree of dispersion (Weisenberger et al., 2007). Oxidative treatments of CNTs are widely used in order to improve the dispersion. The hydroxyl and carboxylic group counteract the Van der Waals forces between CNTs and enhance the interaction with the matrix phase as well as contribute to the major improvement in the dispersion.

Dispersion of additives in the matrix of polymer is the most crucial part in production of composite. There are several methods of the dispersion of CNTs in the polymer matrix are such as solution mixing, melt mixing and in-situ polymerization. Different methods of dispersion give different degree of dispersion of CNTs. N.G. Sahoo et al, 2008 stated that in solution mixing CNTs is dispersed in a suitable solvent and polymers are mixed in solution, then precipitation is formed. They found that a high power ultrasonication process is more effective than simple stirring in forming a

successful dispersion. Ultrasonification can effectively break down the entanglements of CNTs. On the other hands, melt mixing is about mechanically dispersion CNTs into polymer matrix at high temperature and high shear force mixer. This approach is simpler and mostly applied in industry. The high temperature makes sure that the solid form of CNTs and polymer well mixed into each other and the high shear forces help to break nanotubes aggregate or prevent their formation again. The third method is in-situ polymerization which the CNTs are dispersed into the monomer and followed by polymerization process. Higher percentage of CNTs may be easily dispersed by this method and forming a strong interaction with the polymer matrix. This method only limited to prepare nanocomposite that insoluble in solvent and thermally unstable. This method is an alternative method if solution mixing and melt mixing cannot be used.

Usually, melt-mixing method always been considered first in dispersion of CNTs into matrix of polymer especially in industry. Li et al. (2006) clarify that this technique had a more uniform nanotubes distribution and this leads to better mechanical properties of composite. However, there is another alternative ways of production of PC/CNTs composite for laboratory research uses and in smaller scale. Li et al. (2006) and Sahoo et al. (2008) mentioned in their research that the successful of dispersion of CNTs in polymer can be achieved in solution mixing as well if with proper stirring or ultrasonication method. P.M. Ajayan et al. (2003) also mentioned that the solution mixing technique allows modification of the surface treatment without drying, which can reduce the agglomeration.

2.5 Processing Method

There are two steps of processing used for this composite which are extrusion and injection moulding. Twin screw extrusion is generally used comprehensively for mixing and compounding purpose. Extrusion used applied for thermoplastic material. In this process, the rotating mechanical screw is applying pressure to the material to flow. Within the chamber the material is compacted, melted and formed a continuous fluid with a constant diameter (Callister et al., 2008). Solidification of the extruded composite

is carried out passing it through blower, water spray or bath. In order to obtain pellet form, the solidified extruded composite is palletized.



Figure 2.6: Twin screw extrusions

Source: www.rheologysolutions.com

Injection moulding is the next step after pellet form of composite obtained. The pellet is fed from feed hopper into a cylinder by the motion of ram and then the charge is pushed forward into heating chamber. In there it is forced around by spreader so it makes contact with heated wall and melted to form viscous fluid. The molten fluid is injected into the mould cavity through a nozzle. The pressure is maintained until the molten fluid solidified. The mould is open and the piece of product is ejected and then process cycle is repeated. Injection moulding is better choice compared to other moulding as its temperature distribution is more even (William et al., 2008). For example compressing moulding is not suitable to be used in this case. This is due to the pressing technique applied unequal pressure on the moulding and bubbles might forms in the sample which will affect the mechanical properties of composites. Besides, the cycle times are relatively low, and many parts can be made from a single mould, save cost and save time.



Figure 2.7: Injection moulding

Source: www.en-plasinc.com

2.6 Properties of PC/CNTs Composite

CNTs have been proposed for many applications due to its superior mechanical properties. PC has great mechanical properties as well but it fairly resistance to chemicals. After advance research in dispersion of CNTs in PC, PC/CNTs composites believe that posing better properties compared CNTs alone and PC alone. This promotes further development and expands the range of applications of nano-composites. However, the properties might be deviated from result of theory. This might due to CNTs do not dispersed well in the PC fabric and defects in structure of CNTs, shortening the tube length, accumulate of impurities and loss of material during surface treatment. (Tchoul et al., 2007).

2.6.1 Mechanical Properties

The mechanical behaviour of the PC/CNTs composite which is tensile strength is tested by universal mechanical testing (Gedney, 2005) and the standard mould used for tensile testing of plastic is ASTM D638. Engineering stress which denoted as σ is referring to the tensile stress which is the force that been applied per unit area. While engineering strain, ϵ is a measurement of the percentage of change in length of a material as a result of stress. The engineering stress and strain curve is measured by the machine that strains the material at a fixed linear rate and records the stress. The values are then plotted on a graph called as stress-strain curve which as shown in figure 2.8.

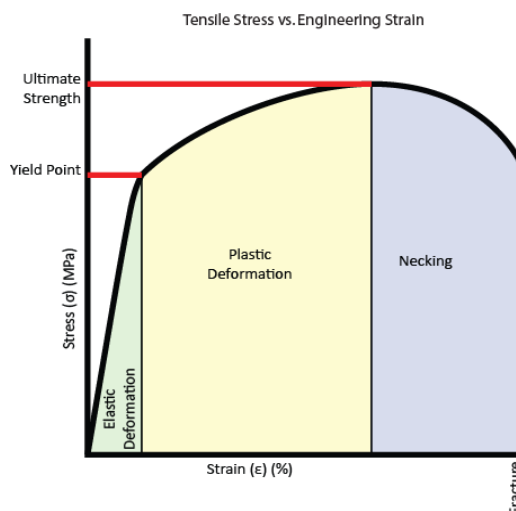


Figure 2.8: Stress-strain curve analysis

Source: <http://www.marcotuts.com>

Based on the stress-strain graph, there are some properties of the material can be determined such as yield point, tensile strength, and elongation et cetera. The definition of the properties that can be identified from the graph is described in the table 2.1.

Table 2.1 Properties based on stress-strain curve

Source: Callister et al., 2008

Properties	Descriptions
Modulus of elasticity	It also known as Young Modulus, which is a constant E of hooke's law. This E constant is the slope of stress-strain graph. It is a measure of the stiffness of a material.
Yield strength	Yield strength is the stress at which the composite become permanently deformed. At yield point, the composite begins to deform plastically. Once it passes the point, the deformation will become permanent; stress is not longer proportional to strain and non-recoverable.
Ultimate strength/ Tensile strength	The maximum stress of a material will withstand when the subjected to the applied strain. If the stress is maintained, the material will fracture.
Elongation	The strain to the maximum load in the tension test or changes in length of material during the testing.
Necking	As the stress increases, the deformation concentrated at a weak point and cause localized reduction in cross section area. The reduction in local cross section area is known as necking.
Toughness	It is a measure of the ability of the material to absorb energy up to fracture.
Ductility	It measures the degree of plastic deformation that has been sustained at fracture.
Brittle	The plastic that experiences a little or no plastic deformation before fracture is known as brittle.

The breaking pattern of a material is also essential information to determine whether the material is brittle or ductile. As been illustrated in figure 2.9, if the material break after long elongation indicates that the material is very ductile, if the material breaks with jagged pattern shows that the material is moderately ductile while if the material break smoothly after small elongation means the material is brittle.

If based on the stress- strain curve analysis, the material with higher strength has steeper slope and higher curve. While the material with higher ductility shows higher strain value. However, if the area under the curve is large, this indicates that the toughness of the material is high.

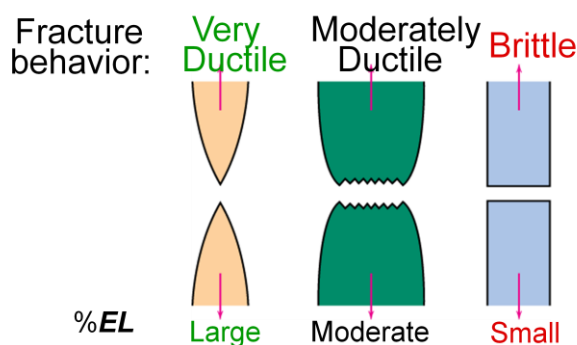


Figure 2.9: Ductility or brittleness of a material

Source: Callister et al., 2008

The incorporation of CNTs into PC matrix can potentially provide a significant increase in mechanical properties (Xie. et al., 2005). This has been proved by Vaisman et al. in 2006, a pure PC modulus a 70% increase was observed due to incorporation of 5 wt% of CNTs. The figure below shows the comparison of pure PC and PC/CNTs

composite. In this research, tensile testing is carried out in order to test whether the dispersion by solution mixing is succeeded or not or else other errors occurred.

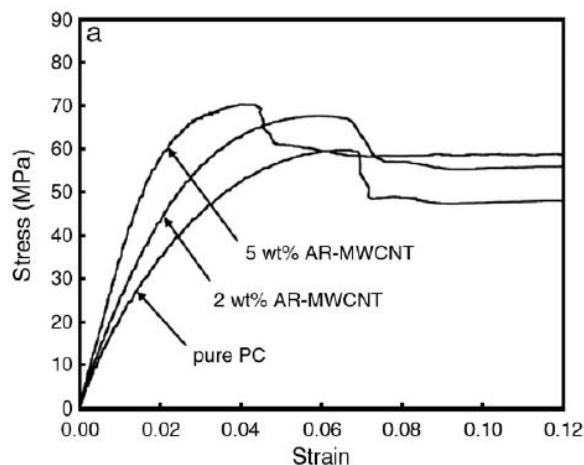


Figure 2.10: Stress-strain curves of PC/MWNT composite and pure PC

Source: Vaisman et al., 2006

2.6.2 Weather/ Ultraviolet (UV) Resistance

Berins (1991) mentioned that the PC polymer material is affected by weathering or ultraviolet radiation. He found that there is slightly change in colour and slight embrittlement can occur on exposure to ultraviolet radiation. In 1999, Lehman R.L et al. stated that the weathering tendency can be stabilized by use proper additives. Through this research, CNTs are used as additives (fillers) in order to improve pure PC weather/UV resistance. The properties of the composite will be checked by tensile testing again in order to distinguish the improvement.

2.6.3 Chemical Resistance

PC is commonly used in applications where contacts with chemicals, detergents or oil is cannot be avoided. Thus, the resistances of PC towards the chemicals are important for protect the health and property of user. Unfortunately, PC has fairly resistance towards chemicals especially to strong acids, strong bases, hydrocarbons and solvents (Fibox, 2007). Chemical attack can cause degradation and failure of product, change in weight and reduction in mechanical properties (Sanders, 2003). This weakness limits the application of PC even though it having excellent mechanical properties. This weakness can be improved by incorporating CNTs as filler in PC. Testing is carried out by observing the physical changes and measuring the mass difference on the pellet samples before and after contact with chemicals (Riberiro et al., 2002). The chemical resistance testing is carried out on pellet form of samples as the surface area of the pellet is large and gives the effect faster. The tables below shows the list of resistance of PC towards some chemicals at room temperature after submerged in to respective chemicals (Bernier et al., 1968).

Table 2.2: Acids resistance of polycarbonate

Source: Bernier, 1968

Chemical	Concentration %	Resistance
Hydrochloric acid	10	Good
	35	Poor
	10	Good
Nitric acid	50	Poor
	70	Poor
Sulphuric acid	70	Good
	90	Fair

Table 2.3: Alkalis resistance of polycarbonate

Source: Bernier, 1968

Chemical	Concentration %	Resistance
Ammonia	10	Good
	20	Fair
	50	Poor
Potassium hydroxide	1	Fair
	concentrated	Poor
Sodium hydroxide	1	Fair
	concentrated	Poor

Keys:

Good: little or no reduction in physical properties, change in weight less than 1% and change in tensile strength less than 5%.

Fair: Reduction in physical properties occurs after long exposure change in weight more than 1% and change in tensile strength more than 5%.

Poor: Noticeable change in physical properties and weight after short time exposure, change in weight more than 1% and change in tensile strength more than 5%.

2.7 Scanning Electron Microscope (SEM)

SEM as shown in figure 2.11 is an instrument that used to examine objects in very fine scale by a beam of energetic electrons. The conventional microscopes have limiting resolution which is 250 nm, which is approximately the wavelength of the incoming light is used to observe the samples. The features of samples that smaller than that cannot be observed anymore and source with smaller wavelength is required.

During SEM inspection, the focused energetic electron beam is scanning on specimen surface and resulting in the transfer of energy to the spot focused. These injected bombarding electrons, also referred to as primary electrons, dislodge electrons from the specimen itself. The dislodged electrons, also known as secondary electrons, are attracted and collected by a positively biased grid or detector, and then translated into a signal. After signal amplification and system analysis, these signals will be transmitted into images of sample topography, and revealed on the screen.



Figure 2.11: Scanning electron microscope equipment

Source: <http://kuchem.kyoto-u.ac.jp>

In order to further observe the dispersion of CNTs in the PC matrix, SEM characterization was performed on the PC/CNTs composite (Li et al., 2004). On the other hands, it also studies in the deformation of the composite after tensile testing. The following is the examples of well dispersed CNTs in PC matrix which obtained from Li et al., 2005 research.

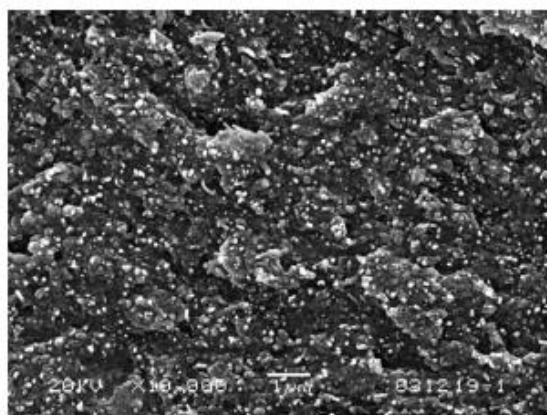


Figure 2.12: Captured figure of well-dispersed CNTs in PC/CNTs composite by scanning electron microscope

Source: Li et al., 2004